

## Editorial Comment

# Frequency Content of Systolic Murmurs: An Answer to the Riddle of Aortic Stenosis?\*

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Systolic murmurs are now generally categorized into ejection and regurgitant varieties, after the original classification proposed by Leatham (1). Although ejection murmurs may originate in the outflow tract of either the left or the right ventricle, ejection from the left ventricle probably provides the most common source for murmur production in human beings, and probably even causes the common innocent murmur of childhood (2-4). Several studies over the past several years (2,3,5-10) have suggested that all murmurs arising in the cardiovascular system are caused by turbulence. Factors that promote turbulence are larger tube diameters, greater fluid (blood) density, lower fluid viscosity and higher flow velocities. The human cardiovascular system, however, with its pulsatile flow and varying arterial diameters, conforms poorly to mathematical rules, and the transition from laminar to turbulent flow probably occurs over a diffuse range of flow rates. Moreover, with abrupt narrowing of orifice size, as seen with valvular stenoses, turbulence can be induced at relatively low flow rates (5). A local obstruction may contain laminar flow within, becoming turbulent downstream as the high velocity jet encounters the slower blood beyond. On the other hand, if there is no internal vessel disturbance and the walls are smooth, laminar flow can be maintained at relatively high flow rates.

## Acoustic Frequency of Murmurs

As might be anticipated, turbulent (chaotic) flow produces a broad range of frequencies, usually bearing little or no relation to one another. Musical murmurs provide an exception to this rule, for they possess geometrically related overtones, most likely caused by the vibration of valvular

or chordal structures in response to high velocity jets. The relative proportion of high frequency components found within most ejection murmurs is directly related to the maximal velocity of blood flow through the originating jet (11). Because velocity varies directly with pressure gradient across a stenotic segment (12), calculations of relative content of high frequencies have given good correlations with obstructive gradients in both peripheral arterial lesions (11,13) and aortic stenosis (14,15). During the course of a given ejection murmur, maximal frequency content is in parallel with murmur intensity; thus, highest frequencies are found in the intense mid-portion, usually in mid-systole (16). For this reason, it would have been anticipated that the best predictor of peak aortic pressure gradient would be the frequency content of the murmur during a brief period of maximal intensity. However, this was not the case in the study of Johnson et al. (15) in this issue of the Journal, possibly because of difficulty in accurate localization of sampling sites. Another observation of physiologic importance by these authors is that aortic root diameter contributes to the frequency spectrum of a murmur: larger aortas cause a shift toward greater proportions of lower frequency waves. Thus, the frequencies reaching the surface of the body are more than a simple expression of jet velocity alone: aortic root diameter and other factors, yet unknown, may also contribute.

Frequency analysis of heart sounds and murmurs has been available for many years (17,18). Early methods employed the use of band-pass filters to assess sound energy within varying frequency domains. Unfortunately, the analog filtration employed by this method causes signal distortion that may be serious enough to invalidate the results (19). For this reason, those working in other fields of science and industry have discarded the technique in favor of analog to digital conversion of sound waves with subsequent performance of Fourier analysis, that is, mathematical breakdown of frequency content. Within the past decade, modern computers have permitted this almost impossible task to be accomplished quickly and inexpensively.

## Noninvasive Methods to Assess Aortic Stenosis

The Doppler technique permits the maximal velocity of the jet within a stenotic aortic orifice to be estimated directly. A simple formula, four times the square of this velocity determination, can then be used to gain a fairly accurate estimate of the transaortic pressure gradient (20,21). Although theoretically simple, this technique is relatively expensive and requires the accurate placement of a continuous wave Doppler beam, without depth resolution, in a parallel direction within the stenotic jet. Needless to say, considerable experience and time may be required for a good study,

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and even those most qualified may not always find it possible to place the beam accurately enough to avoid underestimation of the degree of stenosis.

Phonocardiography with carotid pulse recording can afford another opportunity to estimate severity of aortic stenosis. With increasing severity of stenosis, the peak intensity of the ejection murmur is progressively delayed (22). Murmurs caused by high grades of stenosis are prolonged—often reaching their peak late in systole—to greater than 0.24 second after the QRS onset. Finding such a delay in a given patient (without a left ventricular conduction delay) virtually assures that there will be high grade obstruction, with a systolic aortic pressure gradient greater than 50 mm Hg. Similar findings have also been noted with the use of Doppler determination of the point of maximal systolic velocity (23). Occasionally, however, significant stenosis may be associated with a murmur reaching its peak at less than 0.24 second after the QRS complex. Analysis of the carotid pulse can aid in this discrimination (22,24), but uncertainties may still exist, particularly in the elderly patient (24), thereby indicating the desirability of additional techniques for assessment.

Standard echocardiography may also provide in suitable patients some estimate of aortic valve orifice size, degree of thickening and immobility of the aortic valve and degree of left ventricular hypertrophy, all of which correlate roughly with the severity of stenosis (25). Estimations of severity are particularly difficult to make in the older patient, however, because valvular thickening and calcification often obscure and distort visualization of the valve motion and orifice diameter.

*The foregoing considerations lead us to the conclusion that, although much progress has been made recently in the noninvasive assessment of aortic stenosis, no single test is ideal under all circumstances. Currently various combinations of clinical evaluation, phonocardiography with pulse recording, Doppler echocardiography and standard echocardiography provide considerable information, often influenced by local interest and equipment. Methods that allow for estimates of transaortic pressure gradient, if combined with nuclear or echocardiographic estimates of stroke volume, may even permit derivation of aortic valve area. Spectral analysis of the murmur, providing such an index of pressure gradient, may prove to be a welcome addition to this array of techniques because it is simple and cost effective. Pressing questions need to be answered first for this technique to assume a place in day to day evaluation: Can the results of Johnson et al. (15) be reproduced in other laboratories with different equipment? Will certain types of murmur, such as those containing a musical component, also be amenable to this approach? Will the concomitant presence of other murmurs, such as that of mitral regurgitation, contain enough high frequency components to invalidate the spectral results, even at the aortic area recording site? Will many exceptions to the current trend be encountered,*

*such as the findings in children or in patients after prosthetic aortic valve replacement? It is hoped that these questions will be answered soon, because as clinicians we can use all possible help in evaluating this common disorder.*

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